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Research notes

Calculation of critical resistance in relaxation generators for spark machining

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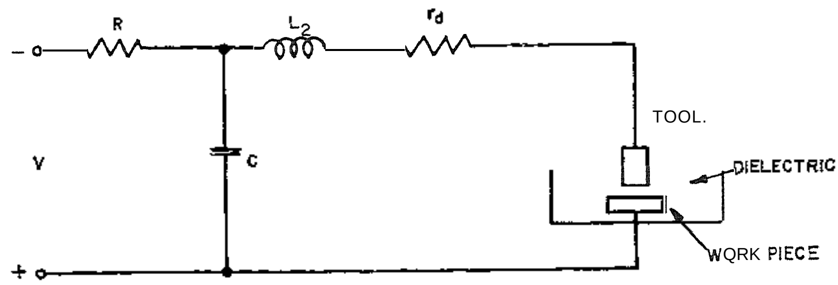
A model for the spark gap in spark machining with relaxation generators is proposed. The model employs a thyristor and a voltage source. This is used to calculate the minimum charging resistance of the relaxation generator for various supply voltages. Experimental values agree **with** the theoretical predictions.

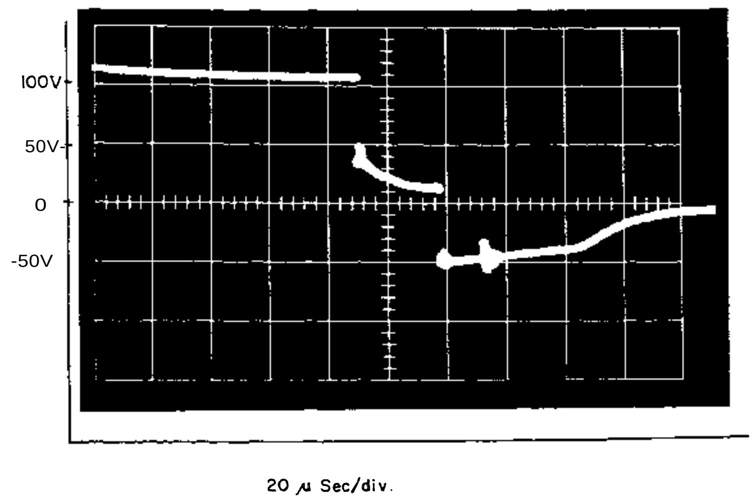
The basic requirement of spark machining with relaxation generators (Lazaranko and Lazaranko 1954) is that current must flow through the spark gap only during the discharge (figure (*a*)). In the ideal case the gap de-ionizes fast after the spark duration before the next spark which occurs only after sufficient voltage is built across the capacitor *C*. In practice, since the d.c. source V is connected to the spark gap permanently, current can flow through the gap even after the end of the spark discharge if an ionized path exists. This results in an arc (Williams 1952). There are many other reasons for the occurrence of arcing or short circuit at the spark gap such as the presence of eroded particles in the spark gap, the inertia of the tool feed control system (Krishnan and Krishnan 1970), roughness of the surfaces machines etc. Even when none of these abnormal conditions exists, the charging resistance R influences arcing. A stable arc will result (Andranov and Chaikin 1949) if the value of the charging resistance is less than $\sqrt{(L_2/C)}$. Barash (1962) has shown that the actual value R_{crit} (critical resistance) which can be used in a practical circuit without arcing is much higher, being $30\sqrt{(L_2/C)}$. Variation of R_{crit} for different voltages *7* in a practical circuit under realistic machining conditions is discussed in this note.

The theoretical derivation of R_{crit} generally assumes that each spark-over takes place at the same voltage. For this to be true the spark gap should be constant. In practical machining the gap is varying from spark to spark. Hence spark-overs occur at any voltage between the maximum supply voltage V and V_2 where V_2 is the voltage below which no sparking can occur (Mironoff 1967).

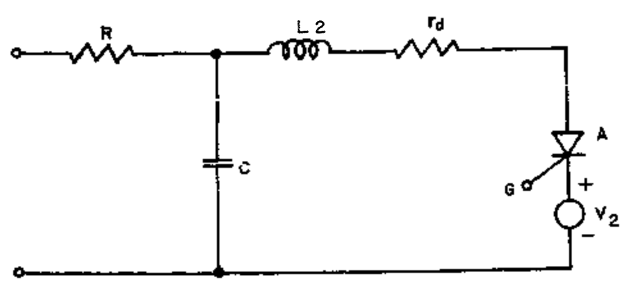
Detailed waveform of a discharge is shown in the figure (6). During discharge the voltage at first falls very fast to a value $V_1 = 40$ v (approx.). Following this there is a comparatively slow fall of voltage lasting for the discharge half period until a value V_2 is reached. V_2 is found to be between 10 and 12 v and independent of the value of the capacitor and the supply voltage. Both Barash (1958) and Zolotykh (1955) have shown that the spark gap displays certain rectifying property in that while the first half wave peak



(a)



(6)



(*c*)

(a) Circuit diagram of relaxation generator. (6) Wave form of a discharge, (c) Spark gap model.

current increases with **(7,** the second reverse peak current is reasonably independent of the value of C.

Combining the invariant V_2 and the rectifying property of the spark gap a model is suggested in the following to calculate the values of R_{crit} **of** relaxation generators. The breakdown of the spark gap and the subsequent 'channel spreading' (Hockenberry and Williams 1966) are analogous to voltage breakdown and current spreading in a thyristor. The transient reverse conduction before de-ionization in a spark gap is also similar to the reverse recovery current in a thyristor. In view of these similarities the proposed model uses a thyristor to represent the spark gap as in the figure *(c)*. The thyristor can conduct only if the voltage at the anode exceeds V_2. An arc may be defined as the condition in which the thyristor fails to commutate resulting in nearly zero voltage across it. As the discharge current is oscillatory, the circuit commutated turn-off time t_c is the discharge half period (G E C 1964) Hence the critical resistance that permits commutation of the thyristor should not charge the capacitor C to a voltage greater than V_2 in a time equal to $T/2$ where T is the discharge period approximately equal to $2\pi\sqrt{(L_2/C)}$.

Linear charging may be assumed as V_2 is usually much smaller than the supply voltage V. Then

$$R_{\text{crit}} > \frac{1}{C} \cdot \frac{V}{V_2} \cdot \frac{T}{2},$$

$$> \pi \frac{V}{V_2} \cdot \sqrt{\frac{L_2}{C}}.$$

In the limit,

$$R_{\text{crit}} = \pi \cdot \frac{V}{V_2} \cdot \sqrt{\frac{L_2}{C}}.$$

Experimental conditions were as follows :

L_2 :	between 2 and 5 μH,
C :	between 1 and 50 μF,
V :	60, 120 and 240 v,
Workpiece :	EN 24 steel/mild steel,
Tool :	copper/brass,
Dielectric :	commercial kerosene.

In all the experiments it was observed that stable machining with slight arcing was possible at the calculated values of R_{crit}. Substantially arc-free machining for long periods of time was, however, possible at values of $R = 1{\cdot}5R_{\text{crit}}$. This is considered to be in good agreement with theory in view of the approximations made and the complexities of the machining process. The calculated R_{crit} gives the minimum charging resistance. Barash (1962) used a supply voltage of 130 v. Taking V_2 as 12 v, we get

$$R_{\text{crit}} \text{ as } \pi \cdot \left(\frac{130}{12}\right) \cdot \sqrt{\frac{L_2}{C}} = 34\sqrt{\frac{L_2}{C}}.$$

This is quite close to Barash's (1958) approximate empirical value of $30\sqrt{(L_2/C)}$.

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